ASTROPOWER, INC.

Manufacturing Technology for High-Performance Optoelectronic Devices

Optoelectronic devices — from light-emitting diodes (LEDs) and solar cells to lasers and detectors — are abundant in everyday life. Millions of LEDs are used in automobile dashboards and consumer electronic products (clocks, radios, VCRs, CD players, coffee brewers, and microwave ovens), as well as in commercial and industrial products such as fax machines, copiers, and printers.

COMPOSITE PERFORMANCE SCORE

(based on a four star rating)

* *

LEDs That are Four Times as Bright

Although LEDs are used in many applications where digital readout is needed, they have limitations. They do not emit much light, so they cannot be seen at a distance. If they produced really bright light, LEDs would be even more widely used than they are already. This ATP project with AstroPower, a small Delaware company incorporated in 1989, developed a new approach to production-scale liquid-phase epitaxy (LPE). The company has fabricated LEDs in a way that significantly increases, by a factor of four, the brightness of the light they emit.

A New Approach

LPE is a widely used technique that involves melting a semiconductor material and letting it crystallize on a substrate. AstroPower's novel enhancement, the first technical goal of the project, involved the use of a thermal gradient that promotes the growth of the epitaxial layer laterally much faster than vertically from the substrate. Company researchers made significant advances in understanding growth processes for compound semiconductor materials and in applying LPE to lateral growth over buried reflectors and other components. The technology can be used for volume production of low-cost compound semiconductor devices — those made from a compound of elements, such as gallium arsenide, rather than a single element.

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A large area solar grade silicon sheet emerging from a silicon growth reactor which incorporates new ATP - funded technology.

AstroPower's second technical goal was to develop the technology to automate the new LPE growth process in integrated factory-scale fabrication equipment. Company researchers succeeded in designing and assembling a modular prototype production growth system that has already significantly shortened production scale-up times for currently fabricated products, as well as for potential products under consideration by customers.

Market Developments Upset Initial Commercialization Plans

Commercialization of the enhanced compound semiconductor devices in high volumes has not yet happened. An initial goal, to produce high volumes of red LEDs, has been stymied by market developments.

PROJECT HIGHLIGHTS

Project:
To develop new crystal growth methods and high-throughput manufacturing technology for fabricating light detectors and emitters with integrated reflecting mirrors.

Duration: 7/15/1992 to 7/14/1995
ATP Number: 91-01-0142

Funding (in thousands):

ATP	$ 1,423	47%
Company	1,580	53%
Total	$3,003	

Accomplishments:
The company achieved the goals of the ATP project: developing new epitaxial growth methods, as well as new processes for plant-scale industrial production operations. Evidence of the company's achievements are that it:

- received four patents related to the ATP project technology;

"Columnar-Grained Polycrystalline Solar Cell and Process of Manufacture"
(No. 5,336,335: filed 10/9/1992, granted 8/9/1994)
"Hetero-Epitaxial Growth of Non-Lattice Matched Semiconductors"
(No. 5,356,509: filed 10/16/1992, granted 10/18/1994)
"Columnar-Grained Polycrystalline Solar Cell and Process of Manufacture"
(No. 5,496,416: filed 8/5/1994, granted 3/5/1996)
"Semiconductor Device Structures Incorporating "Buried" Mirrors and/or "Buried" Metal Electrodes"
(No. 5,828,088: filed 9/5/1996, granted 10/27/1998);

- demonstrated the application of the new epitaxial production technology to optoelectronic device structures that have integrated reflecting mirrors for enhancing light output (an ultrabright light-emitting diode (LED) with buried reflectors), achieving a fourfold increase in brightness;

- completed scale-up of liquid-phase epitaxy (LPE)-growth technology to a high-throughput, production-scale process;

- significantly shortened production scale-up times for specific products, compared with previous manufacturing processes;

- constructed a demonstration production facility to implement the technology; and

- conducted an initial public offering of stock in February 1998, raising $16.7 million.

Citations by Others of Project's Patents: See Figure 1.

Commercialization Status:
Direct commercialization of ultrabright red LEDs, a proposed initial goal of the project, did not occur, mainly due to economic and market developments. Knowledge of new crystal growth methods acquired during this project contributed, however, to the enhancement of fabrication methods for the company's Silicon-Film™ solar cell and for other compound semiconductor devices.

Outlook:
AstroPower has applied the ATP-funded crystal growth technology to its current manufacturing processes, improving productivity and lowering costs. It also plans to use the technology for several breakthrough devices when appropriate market size has been achieved; if such markets develop substantially, the outlook is promising. Two significant products that are nearing introduction are combustion sensors based on gallium-phosphorus compounds, and avalanche photodiodes and detectors based on indium-gallium-arsenic-antimony compounds.

Composite Performance Score: * *

Number of employees: 86 at project start; 160 at the end of 1997

Company:
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Solar Park, 461 Wyoming Road
Newark, DE 19716-2000

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Phone: (302) 366-0400

The Japanese have come to dominate the market for red LEDs, which have become a commodity product. Although AstroPower has a technical advantage in producing the devices, the value of this market to the company is quite small, since the cost of entering the market is too high to make such a venture profitable.

Use of the Technology for Current Product Lines

Knowledge developed in the ATP-funded project, especially advances in understanding epitaxy technology, has proven useful across all company production activities, AstroPower officials say. They report that the company's product lines have all grown rapidly in recent years, and they attribute much of the growth to the ATP project. All of AstroPower's compound semiconductor-based products incorporate epitaxial growth in their fabrication. This includes their

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flagship product, the Silicon-Film™ solar cell. Silicon-Film™ is a continuous production process to manufacture crystalline silicon sheets and layers.

Shortened Production Scale-Up Times

The success of the ATP-funded project ensures that new and innovative optoelectronic devices will have significantly shorter production scale-up times than were possible before the project. The establishment of

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a technology that permits low-cost, high-throughput synthesis of compound semiconductor structures is potentially useful for many optoelectronic device products. It can be used, for example, in making specialty devices on a job-order basis using gallium arsenide, gallium arsenide-on-silicon, indium phosphorus, and a host of other unexplored alloys. These devices are used in the fabrication of common products like detectors, solar cells, sensors and light-emitting products. The new technology can also be used in the production of highly sophisticated devices such as vertical cavity surface emitting lasers and resonant optical cavity detectors with back reflectors.

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AstroPower intends to incorporate this technology in a number of breakthrough devices that it can produce in sufficiently large quantities when appropriate market size has been achieved. Two significant applications are nearing product introduction. The first is combustion sensors, based on gallium phosphorus compounds, that can be used for flame control in internal combustion engines and utility burners. The second is avalanche photodiodes and detectors, based on indium-gallium-arsenic-antimony and indium-arsenic-antimony-phosphide compounds, that can be used for light direction and range instruments, collision avoidance, atmospheric gas measurements, weather prediction, spectroscopy, blood gas analysis, and noninvasive medical analysis. These two products are currently in pilot production and are being tested by NASA, the Air Force, and industrial companies.

Company Growth

At the beginning of the ATP project in 1992, AstroPower had annual product sales of $1 million. By 1997, sales had grown to $16 million. And in February 1998, AstroPower successfully conducted an initial

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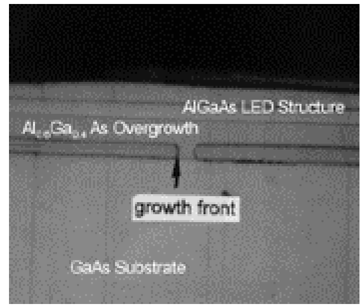

Cross - sectional photomicrograph of a light emitting diode showing device active layers and buried mirror overgrowth.

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AstroPower is convinced that had it not conducted the ATP-funded project, its growth experience (as measured by product sales) would have been set back by three years, the length of the ATP project. This belief is based on the use of improved epitaxial growth technology across all of its product lines, its application of manufacturing automation processes to all of its manufacturing operations, and to the overgrowth of semiconductor materials on dissimilar substrates as well as on mirrors, insulators, and conducting planes. Without the ATP funds, AstroPower says it would not have carried out the project.

Potential Large Economywide Benefits

AstroPower noted at the beginning of its ATP project in 1992 that it expected in a project like this that products might take as long as 10 years to move from initial technology development to new product sales. The demonstration production facility AstroPower developed is capable of producing millions of LEDs or other LPE-based optoelectronic devices per month. When sufficient demand for the new products emerges, AstroPower plans to construct an optoelectronic semiconductor chip-manufacturing facility for new products made possible by the innovative LPE-growth technology.

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Benefits are already accruing to purchasers of the company's solar cells, which have higher quality and cost less than they did before the ATP project. If the company succeeds in bringing to market additional products that use the new technology, even more benefits will accrue to its customers. Because of substantial uncertainty about these events, it is too speculative at this time to try to predict the magnitude of these future benefits.

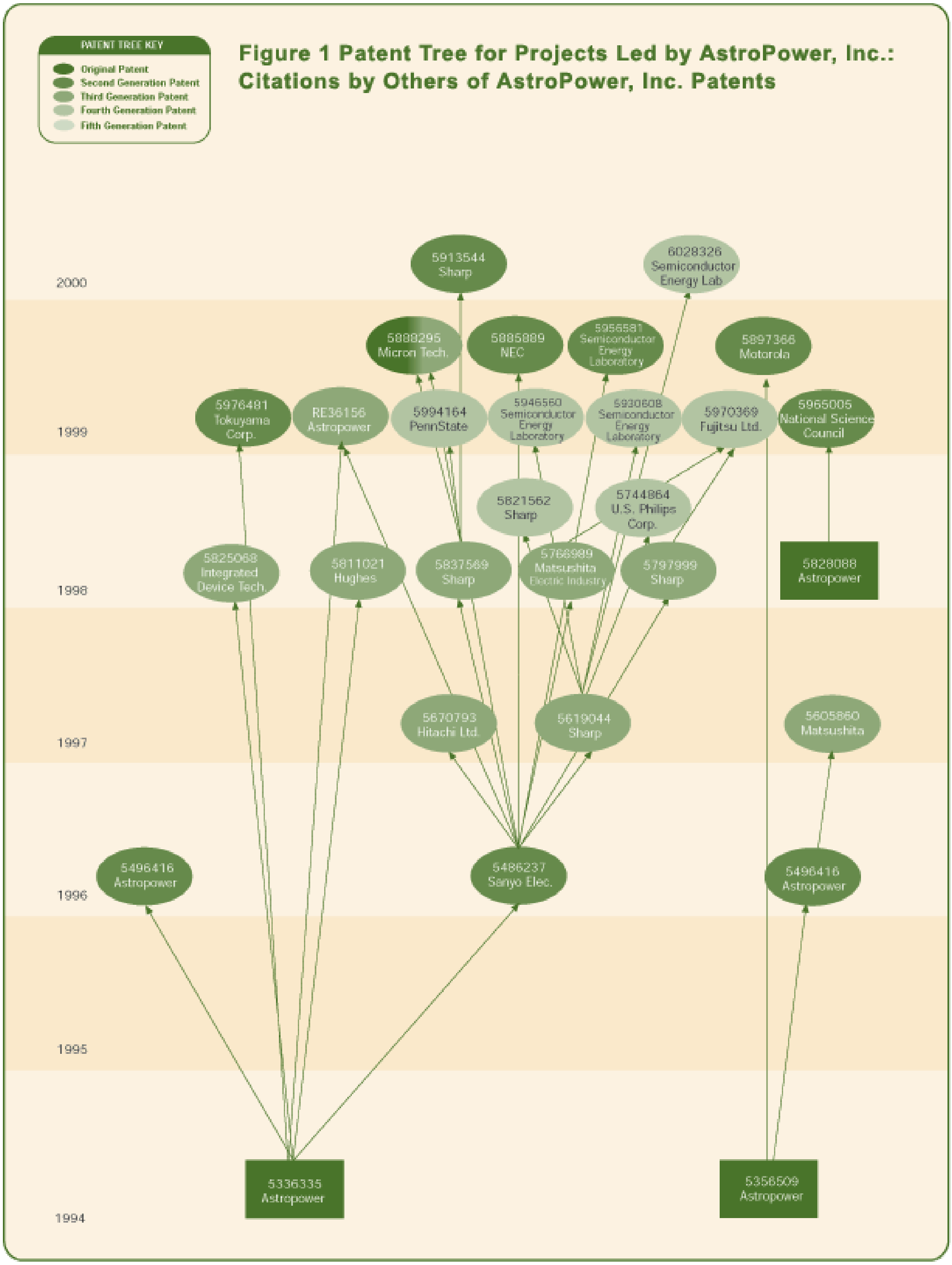

Figure 1 Patent Tree for Projects Led by AstroPower, Inc.: Citations by Others of AstroPower, Inc. Patents

This status report was written during 1997-1998 and published in March 1999.